TOA Radiative Flux Diurnal Cycle in Convective Regions from CERES and Reanalysis

J. Brant Dodson and Patrick C. Taylor

NASA Postdoctoral Program, NASA Langley Research Center

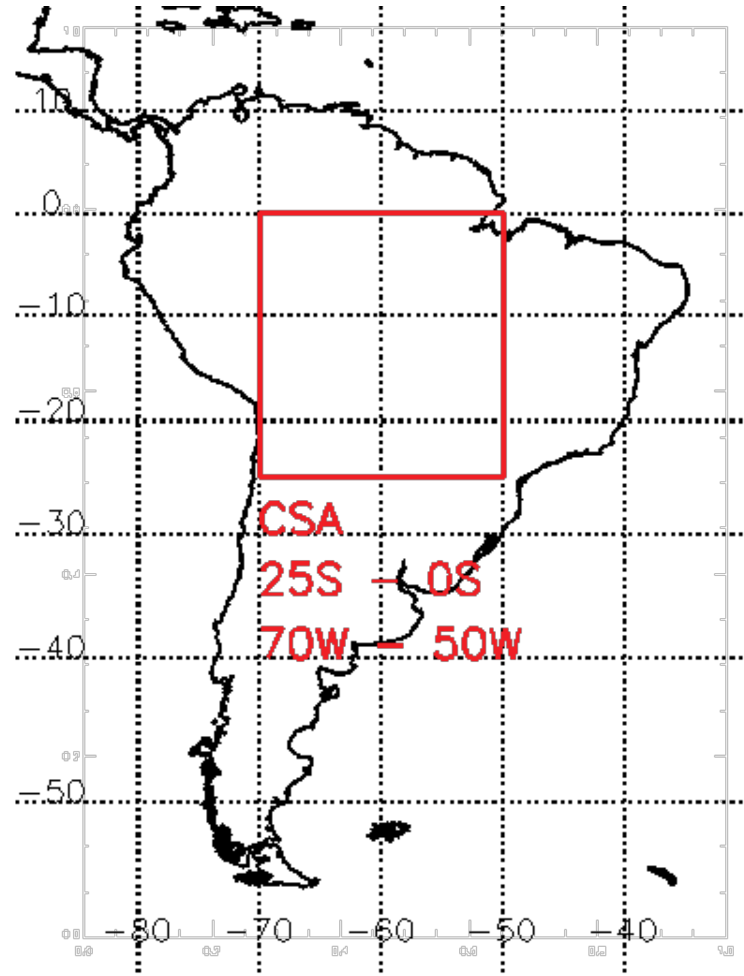
CERES Science Team Meeting

28 September 2017

NASA
POSTDOCTORAL PROGRAM
Administered by USRA

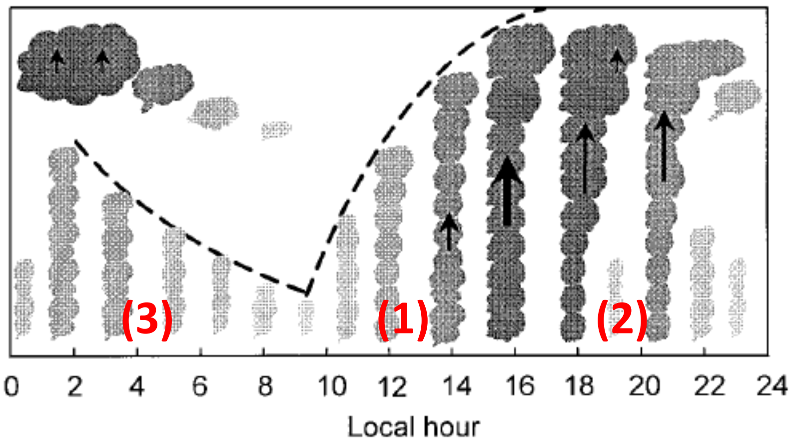
Introduction

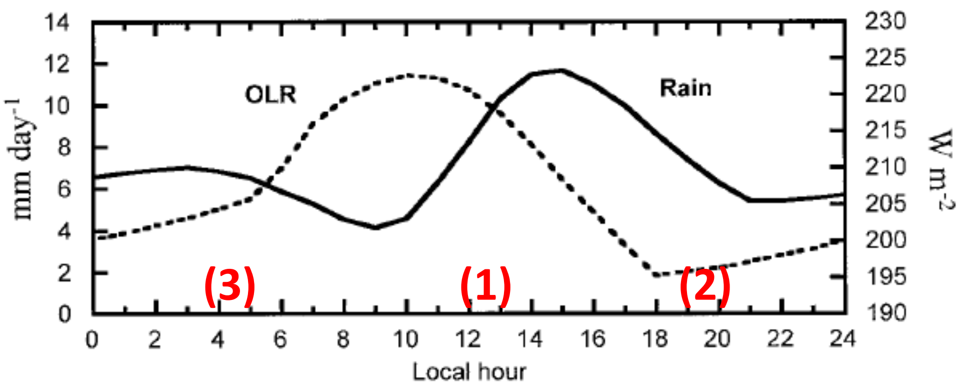
- Diurnal cycle in cloud properties strongly influence diurnal cycle in TOA flux
- Importance of the diurnal cycle
  - Modulates hydrologic cycle and radiative budget
  - Influences long-term radiative variability
- Recent research indicates that in convectively active regions, there is enough variability on monthly time scales to contribute to the total interannual variability of TOA flux balance by up to 7 W m-2 (80%) [Taylor 2014]
- In order to simulate TOA flux realistically, we must understand the causes for monthly variability in the TOA flux diurnal cycle
- Diurnal cycle in cloud properties strongly influence diurnal cycle in TOA flux

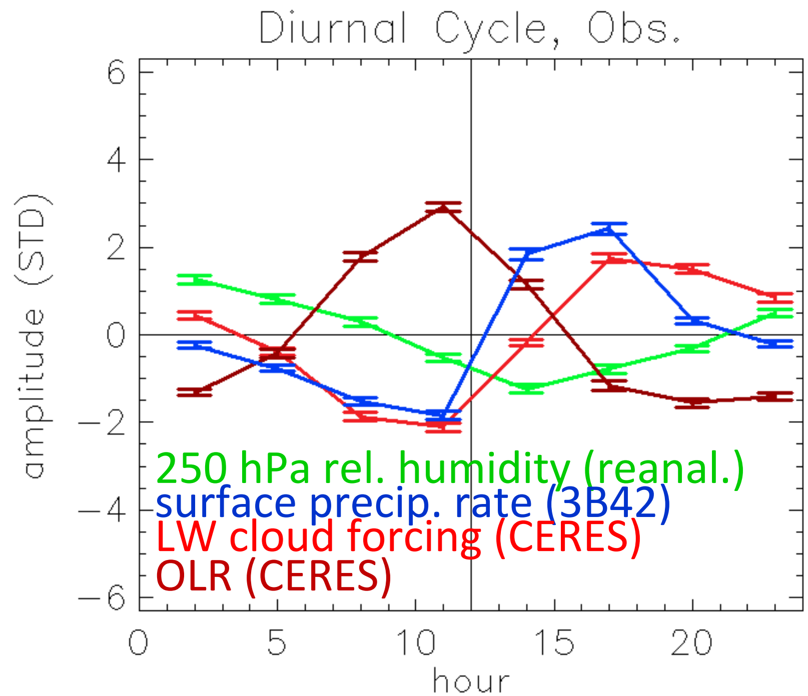


Amazonian Convective Diurnal Cycle (CDC)

1. rapid transition from shallow to deep conv.
2. transition from deep conv. to MCSs and remnant anvils
3. slow transition back to shallow conv.



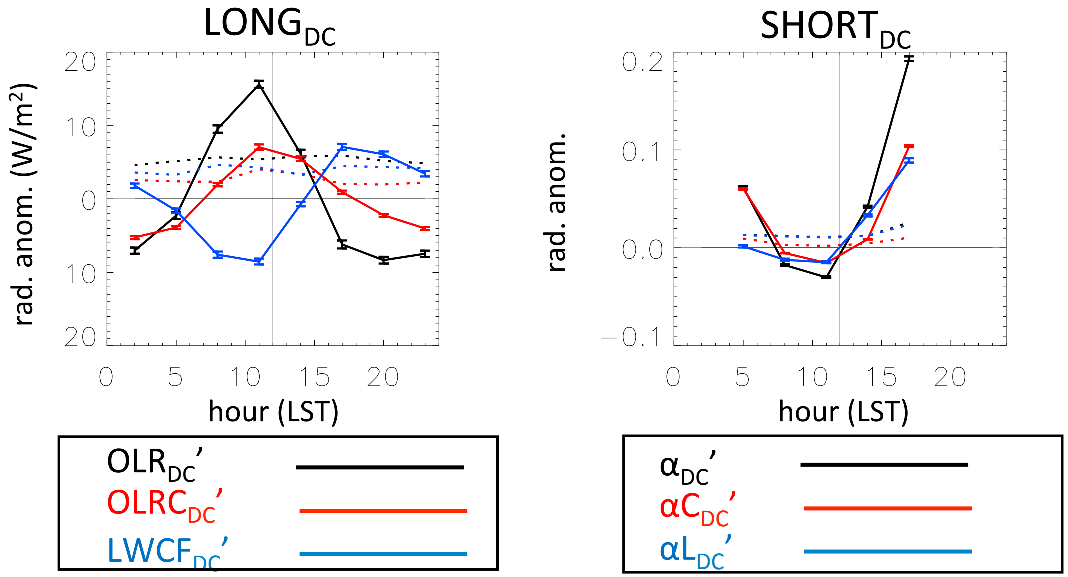




[left] adapted from Lin et al. (2000), Fig. 17 a-c

Amazonian radiative diurnal cycle

CERES SYN1DEG

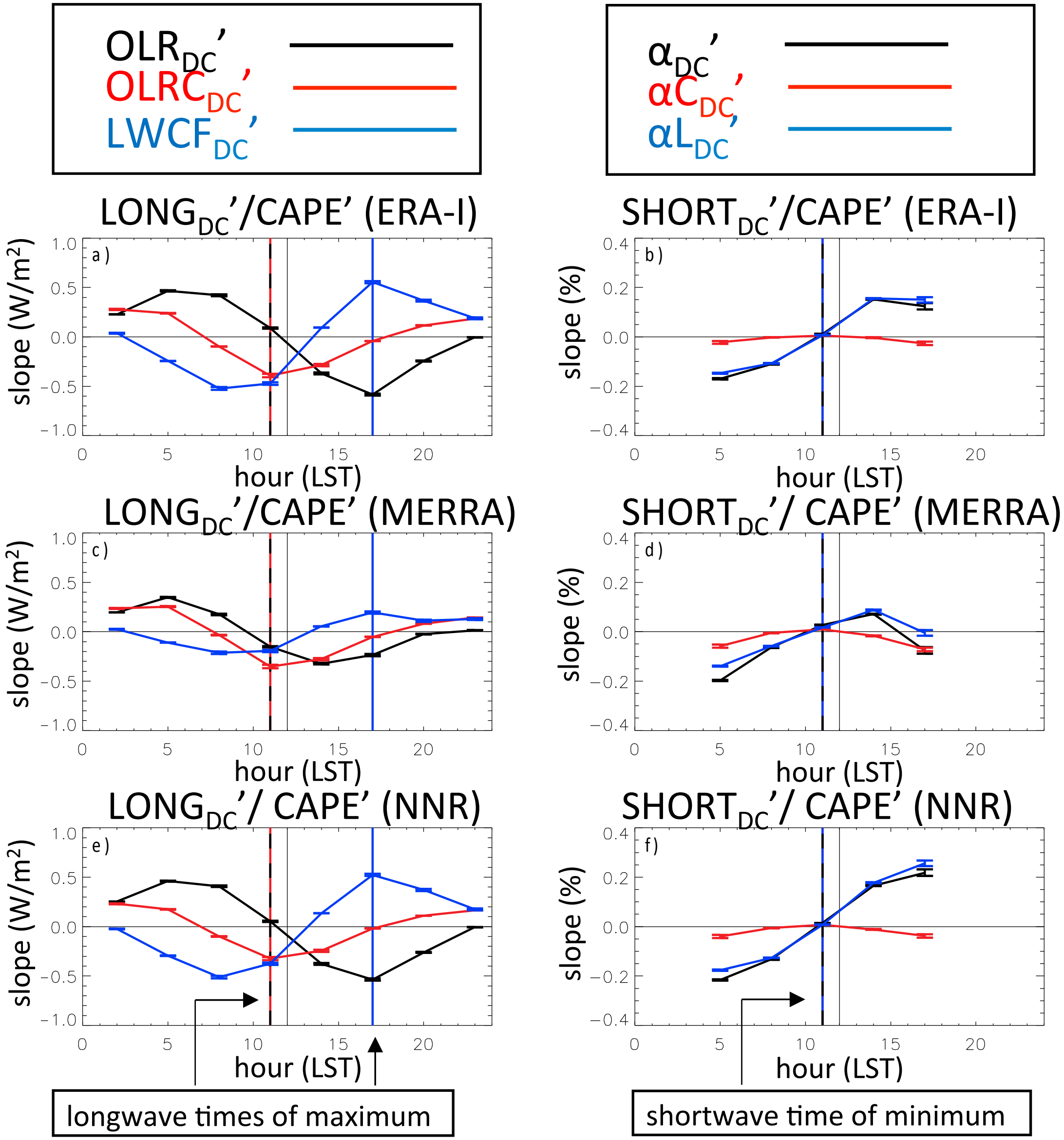


- CERES observations show that both clear sky and cloud diurnal cycles influence the OLR diurnal cycle
- Clear sky follows diurnal cycle of surface heating
- Cloud effect follows the convective diurnal cycle, and shifts the OLR diurnal cycle earlier in the day
- Albedo diurnal cycle is mainly controlled by diurnal cycle in solar incidence angle
- Clouds decrease (increase) morning (afternoon) albedo

Diurnal cycle sensitivity to reanalysis atmospheric state

- Previous efforts use multiple atmospheric state variables to characterize monthly variability in the convective environment
- Common examples: 500 hPa vertical velocity, CAPE, upper tropospheric humidity, lower tropospheric stability, etc.

Diurnal cycle sensitivity to reanalysis atmospheric state [from Dodson and Taylor 2016]

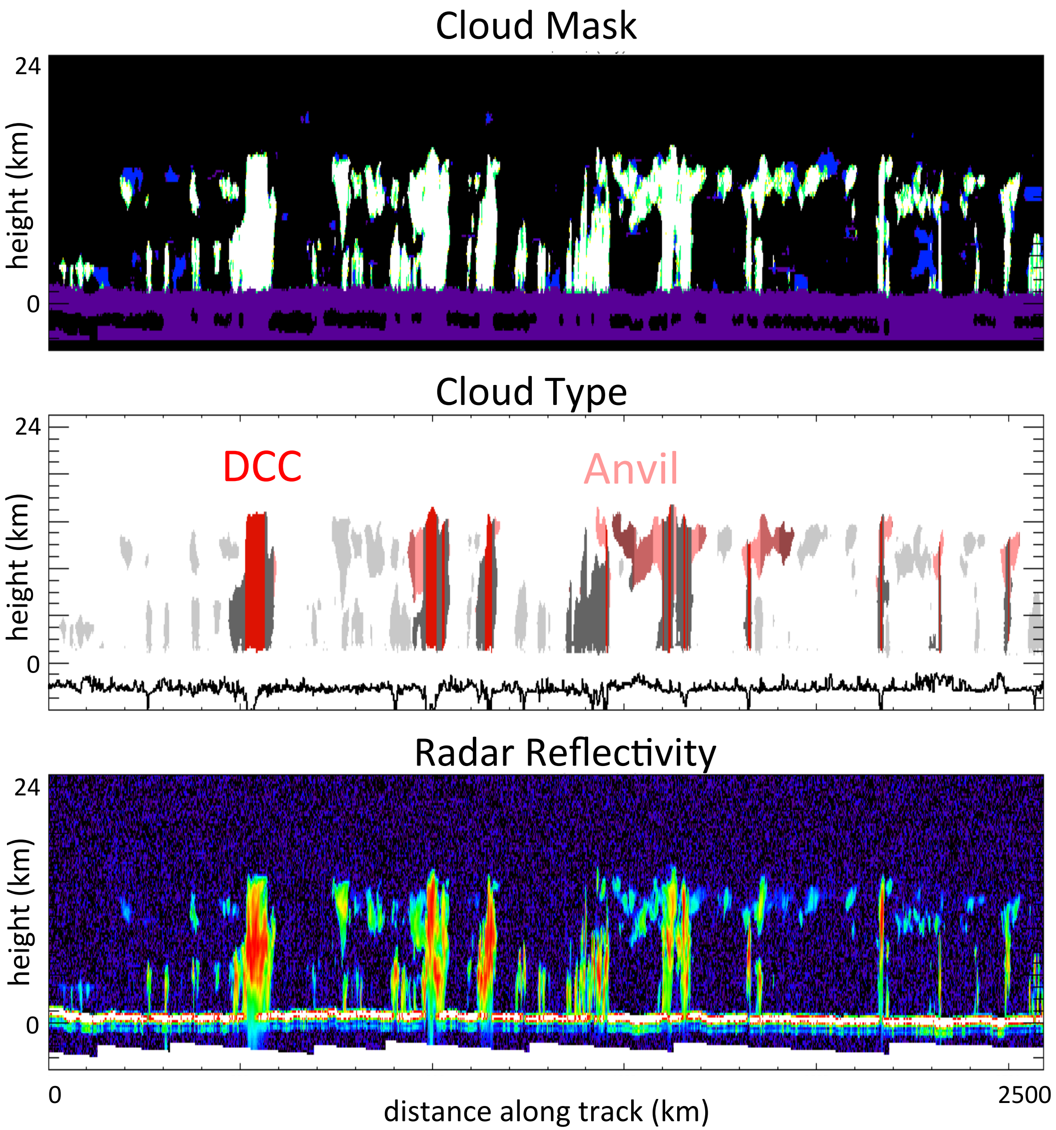


- The monthly anomalies in diurnal cycle of TOA flux variables (3 hr resolution) are regressed against anomalies of atmospheric state variables
- Increased CAPE shifts the time of maximum OLR earlier in the day, and increases afternoon albedo while lowering morning albedo
- For OLR, both the cloud radiative effect and the clear sky effect control the diurnal cycle sensitivity, but the cloud effect is probably the larger effect
- For albedo, the cloud effect is by far the primary driver of the albedo diurnal cycle sensitivity
- Reanalysis results for ERA-Interim, MERRA, and NCEP/NCAR Reanalysis disagree on the magnitude of the longwave sensitivities, and the shape of the albedo curves in the late afternoon

Alternatives to conventional atmospheric state variables

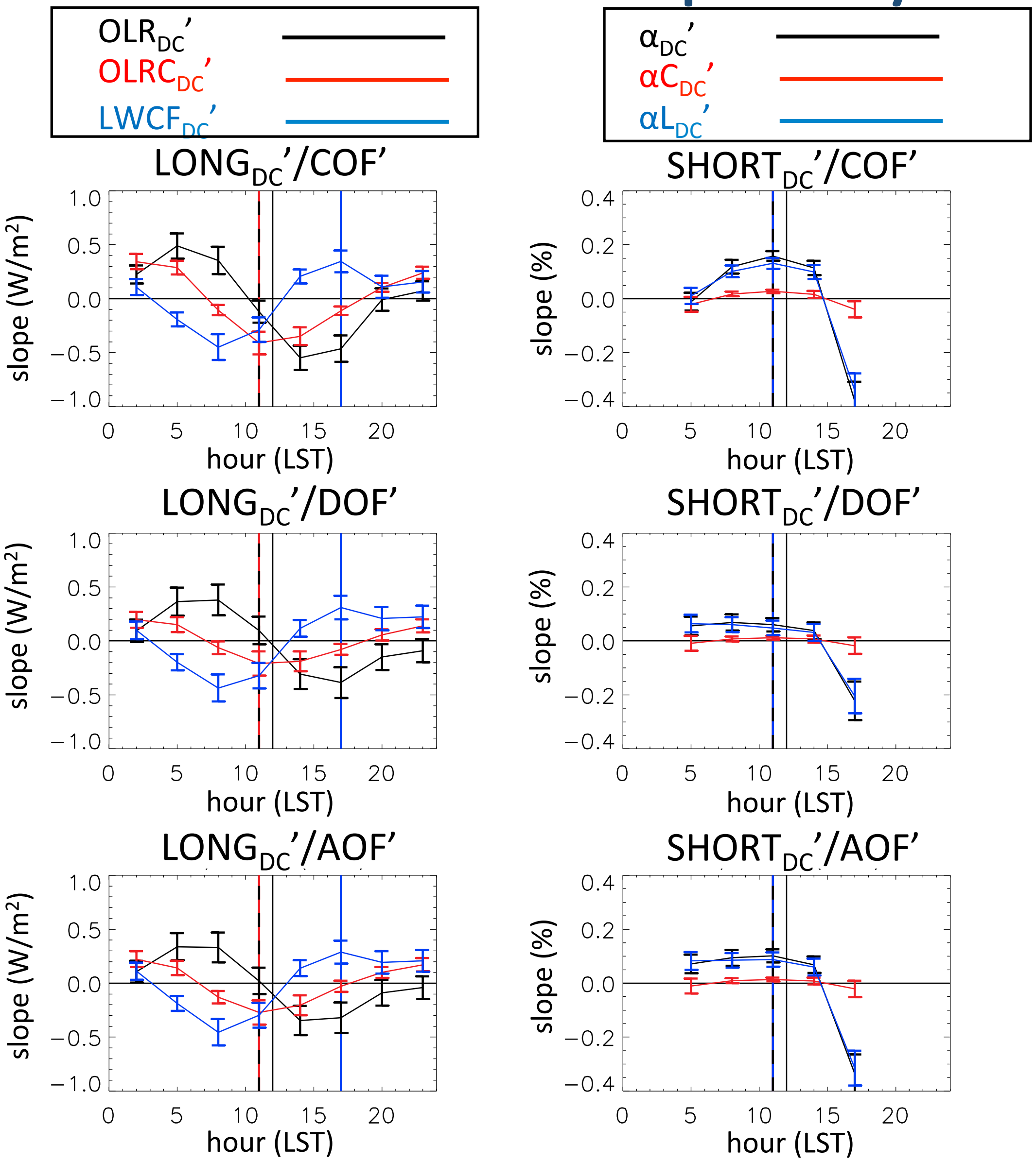
- Satellite observations of clouds can be used as an alternative to reanalysis information of the convective environment
- CloudSat offers observations about several different aspects of convection that may be useful for characterizing monthly convective activity

CloudSat Data – Identifying convection



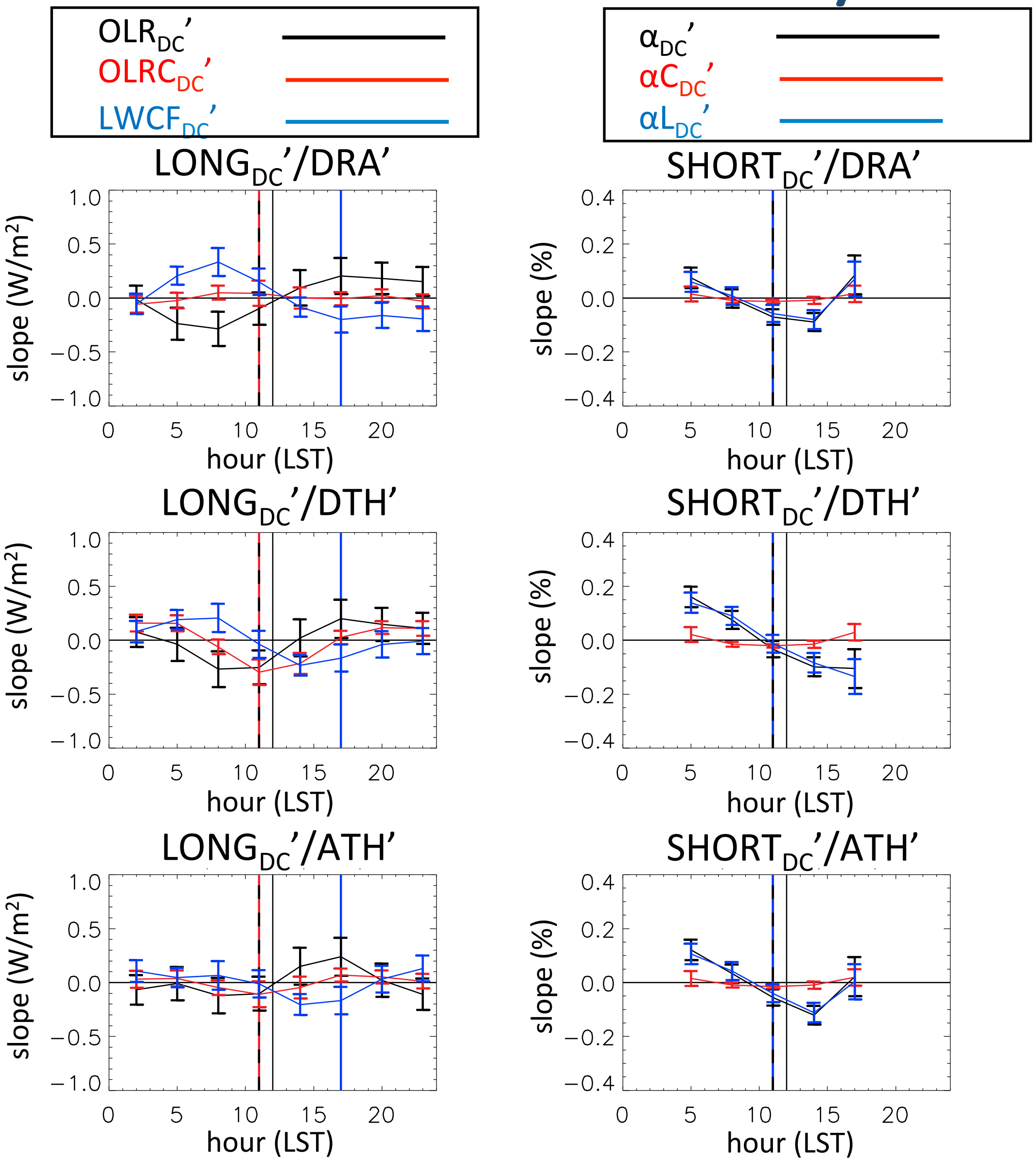
- CloudSat can be used to identify deep convective cores (DCCs) and associated anvil clouds
- DCCs are identified by height and reflectivity criteria, on a single vertical profile basis
- Anvils are identified as middle- to high clouds that are contiguously attached with a DCC

Diurnal cycle sensitivity to CloudSat convective frequency



- The most simple is cloud occurrence frequency, for all clouds (COF), DCCs (DOF), and anvils (AOF)
- The longwave sensitivity to COF' monthly variability closely resembles the sensitivity to CAPE' in both timing and amplitude
- The results for COF', DOF', and AOF' closely resemble each other
- The shortwave results differ from the CAPE' results

Diurnal cycle sensitivity to CloudSat convective intensity and top height

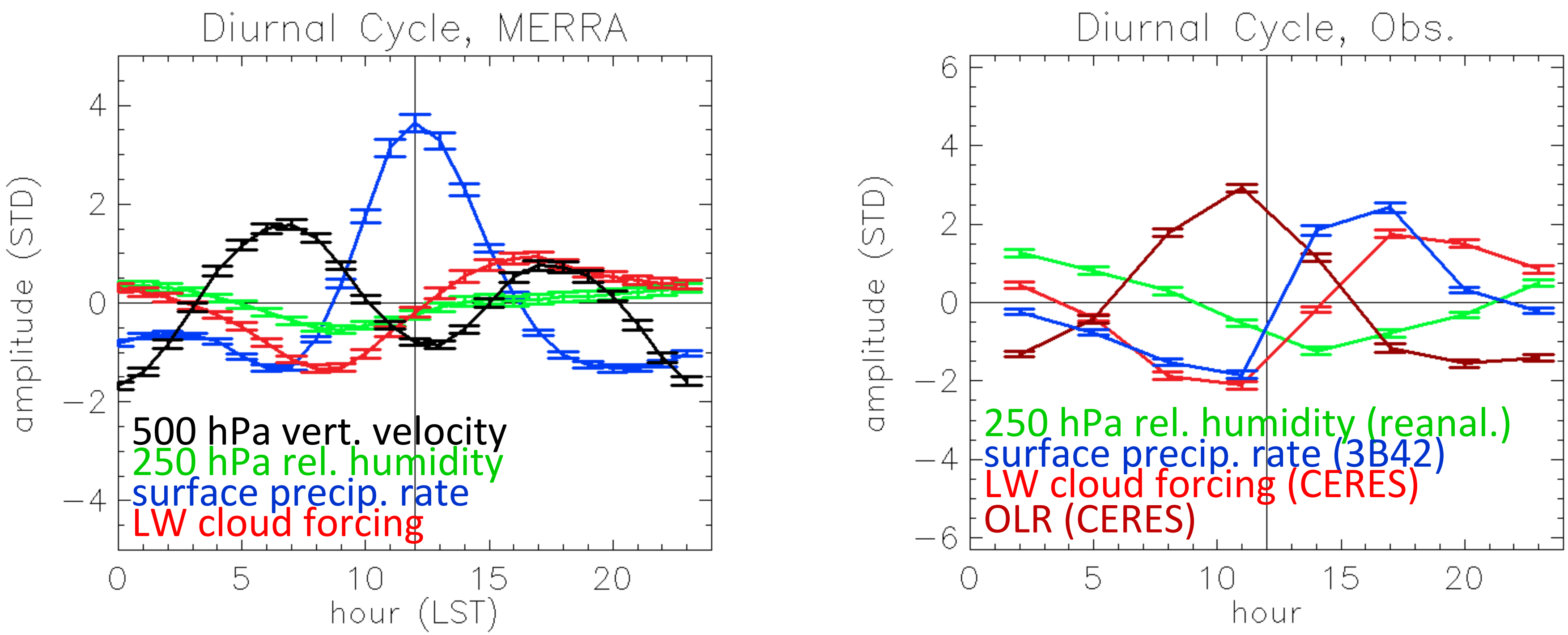


- The DCC upper cloud reflectivity anomaly (DRA) is a proxy for the updraft intensity
- The longwave and shortwave sensitivities to DRA’ are the opposite of the sensitivity to cloud frequency
- The cloud top heights for DCCs (DTH) and anvils (ATH) are often used as proxies for convective intensity
- The DTH’ and ATH’-based results also have the opposite sign to cloud frequency, as well as smaller magnitude for longwave
- Different metrics for convective intensity give different answers

Convective diurnal cycles in MERRA(2)

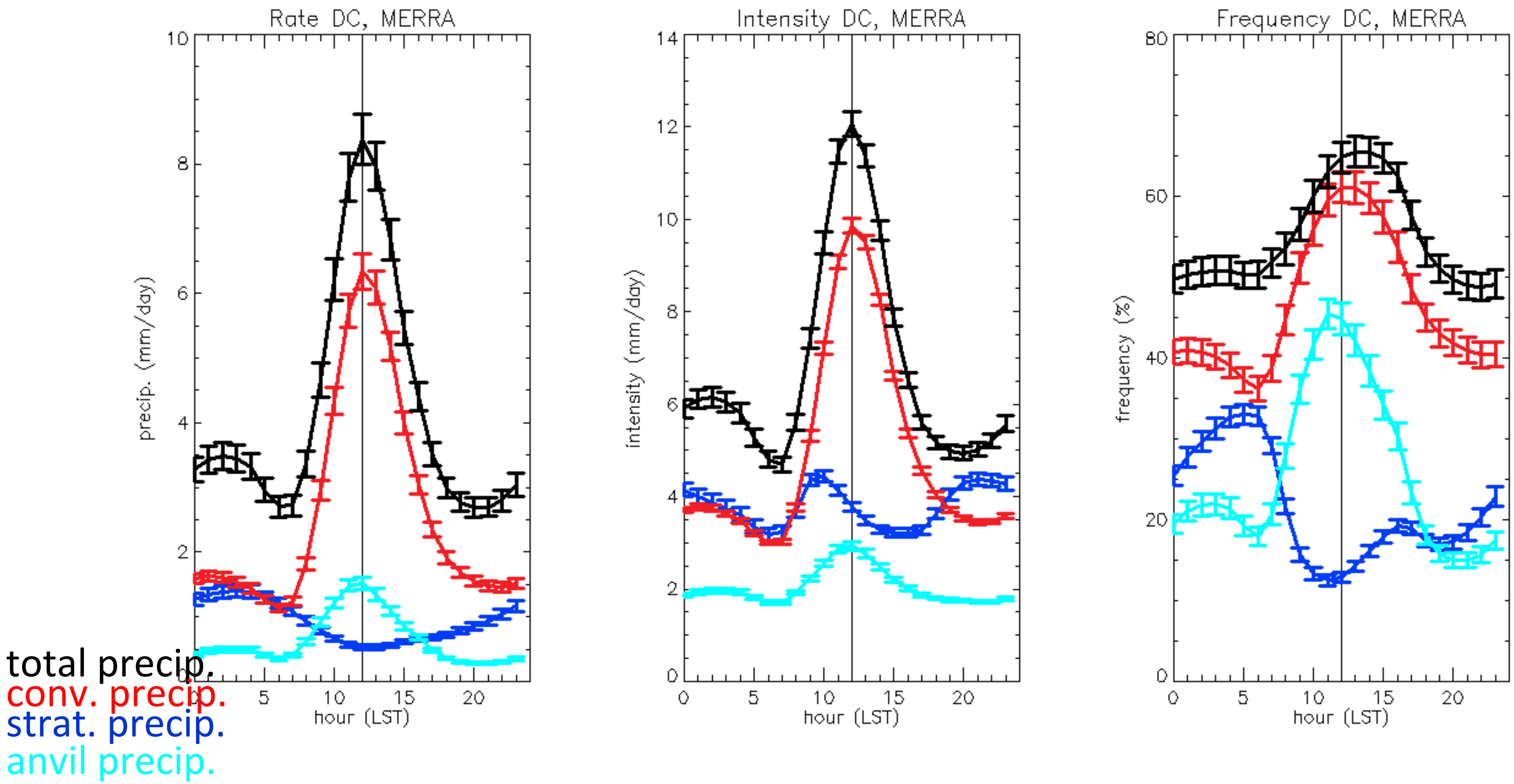
- The convective diurnal cycle (CDC) has been an ongoing topic of difficulty for GCMs and related retrospective analysis products (reanalyses)
- Examination of reanalysis CDC in Amazon reveals significant interesting disparities between observations and models

MERRA CDC



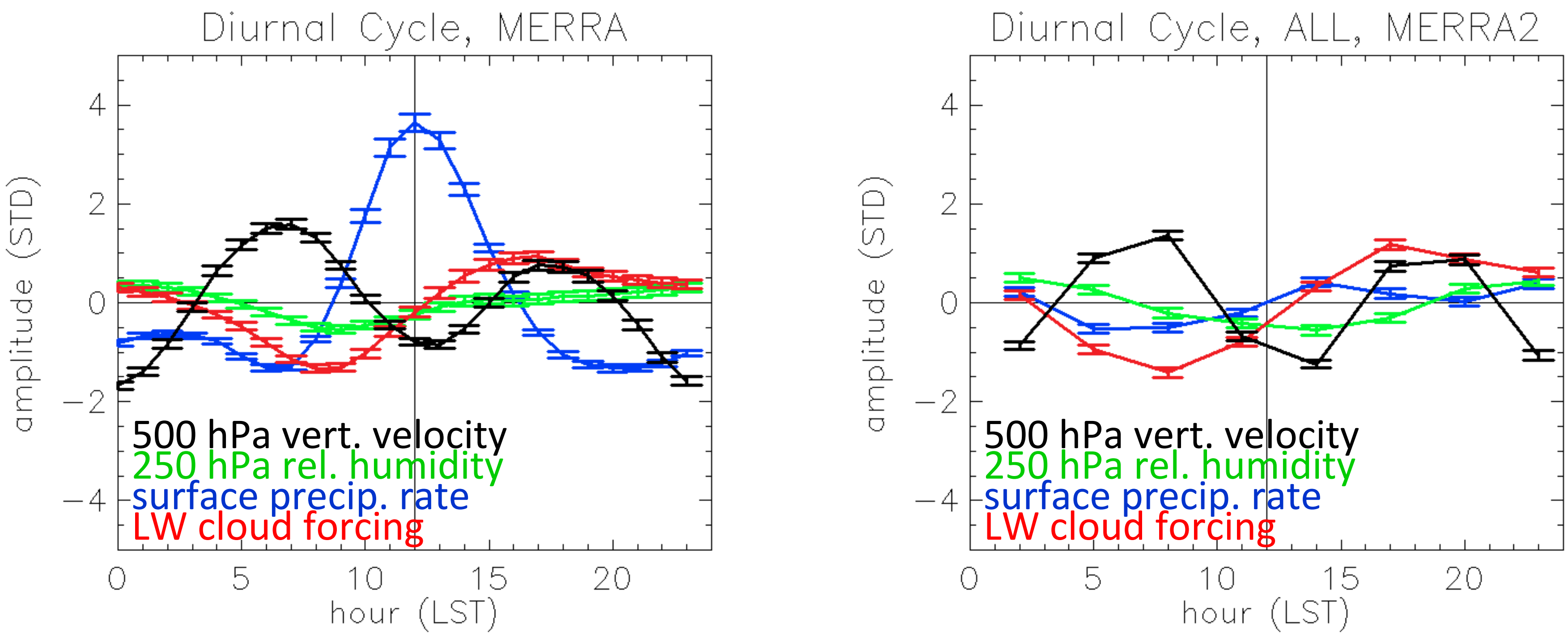
- Analysis time: June 2002 – Oct 2012
- Precip. maximizes at noon, and has secondary max. at 0200 LST
- 500 hPa vert. velocity has prominent semi-diurnal cycle

MERRA Precip. by Source and Component



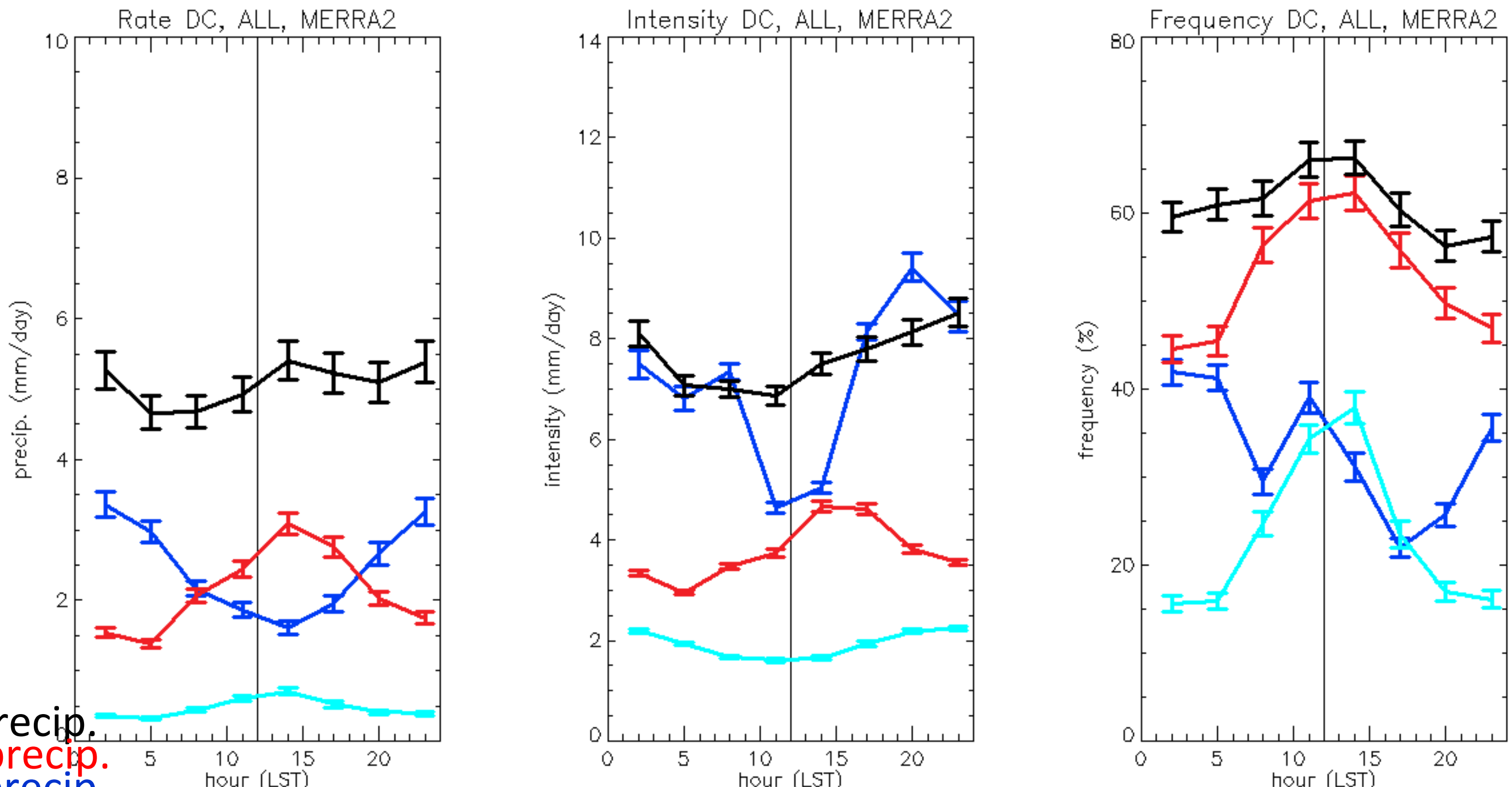
- Both conv. and strat. precip. contribute to nocturnal maximum
- Precip. rate is controlled by both intensity and frequency
- Conv. freq. and intensity have same timing, but strat. has offset timing

MERRA2 CDC



- MERRA2 assimilates observations of precip. (in situ and satellite) to correct AGCM precip.
- MERRA2 now has realistic early-afternoon precip. max., but also nocturnal secondary max.
- Vert. velocity still has semi-diurnal cycle

MERRA2 Prec. by Source and Component



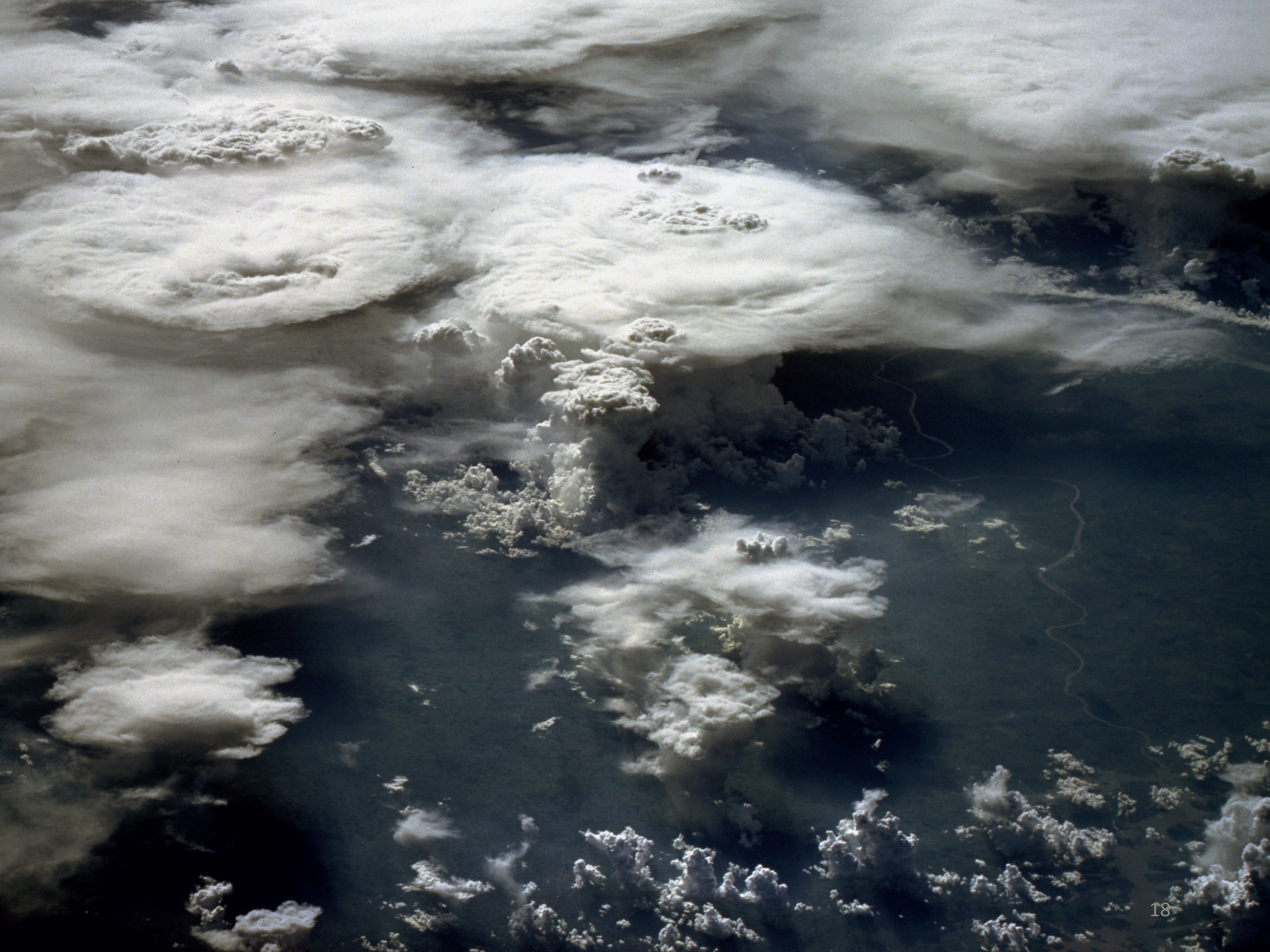
total precip.
conv. precip.
strat. precip.
anvil precip.

- Precip. rate diurnal cycle amplitude is much smaller than observed
- Nocturnal maximum is caused by strat. precip.
- Daytime conv. frequency (strat. intensity) causes daytime (nocturnal) precip. max
- Posible explanation: semi-diurnal tide?

Conclusions

- The CloudSat sensitivity results depend strongly on which index of convective activity is used
- MERRA 500 hPa vertical velocity has unrealistic semi-diurnal cycle, which MERRA2 (mostly) does not resolve
- Errors in MERRA CDC are related to more than convective parameterization, but are a multi-faceted problem
- MERRA2 trades precipitation timing problem with precipitation amplitude

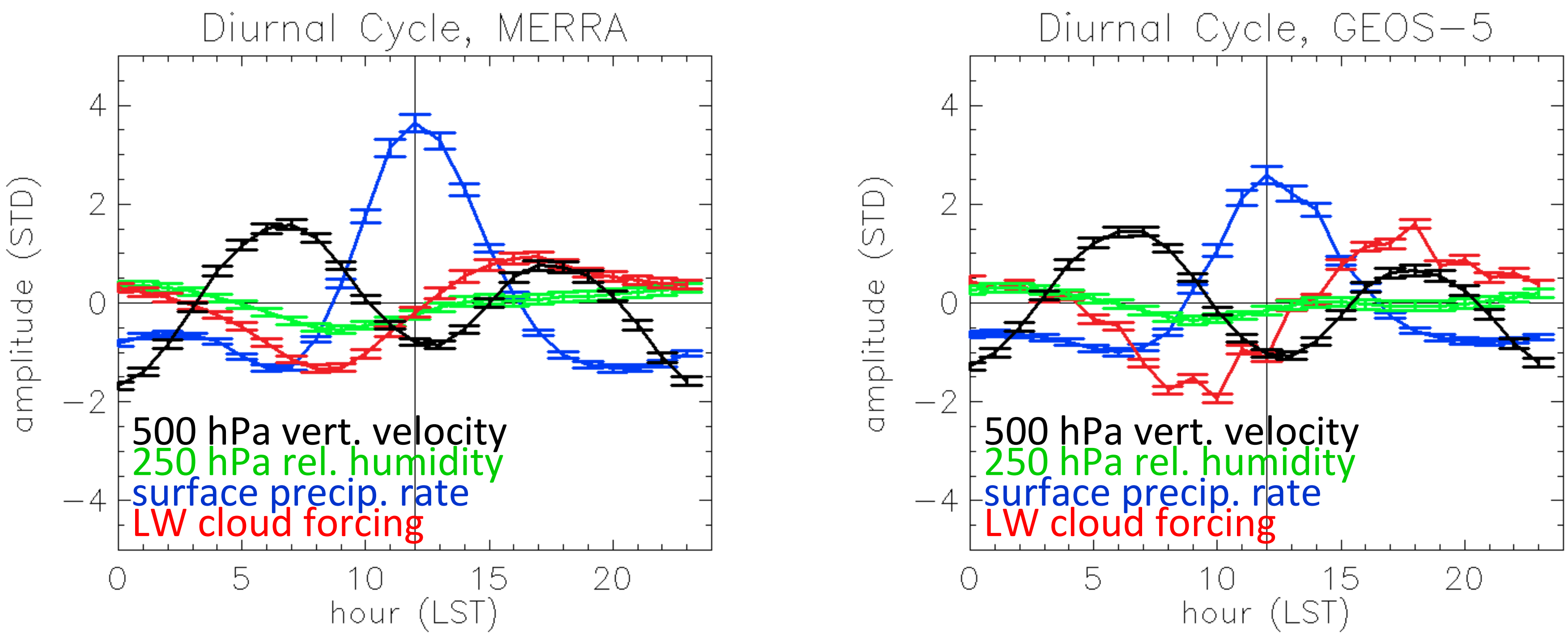
fin



[EXTRA] Data Sources

- CERES
  - observes diurnal cycle of TOA flux
  - diurnal cycle enhanced by geostationary observations
- Reanalysis
  - three used for comparison
    - ERA-Interim
    - MERRA
    - NCEP/NCAR Reanalysis (NNR)
  - used to estimate monthly variability of CAPE, upper tropospheric humidity, lower tropospheric stability, etc.
- CloudSat
- used to observe convective anvils, upper convective cores

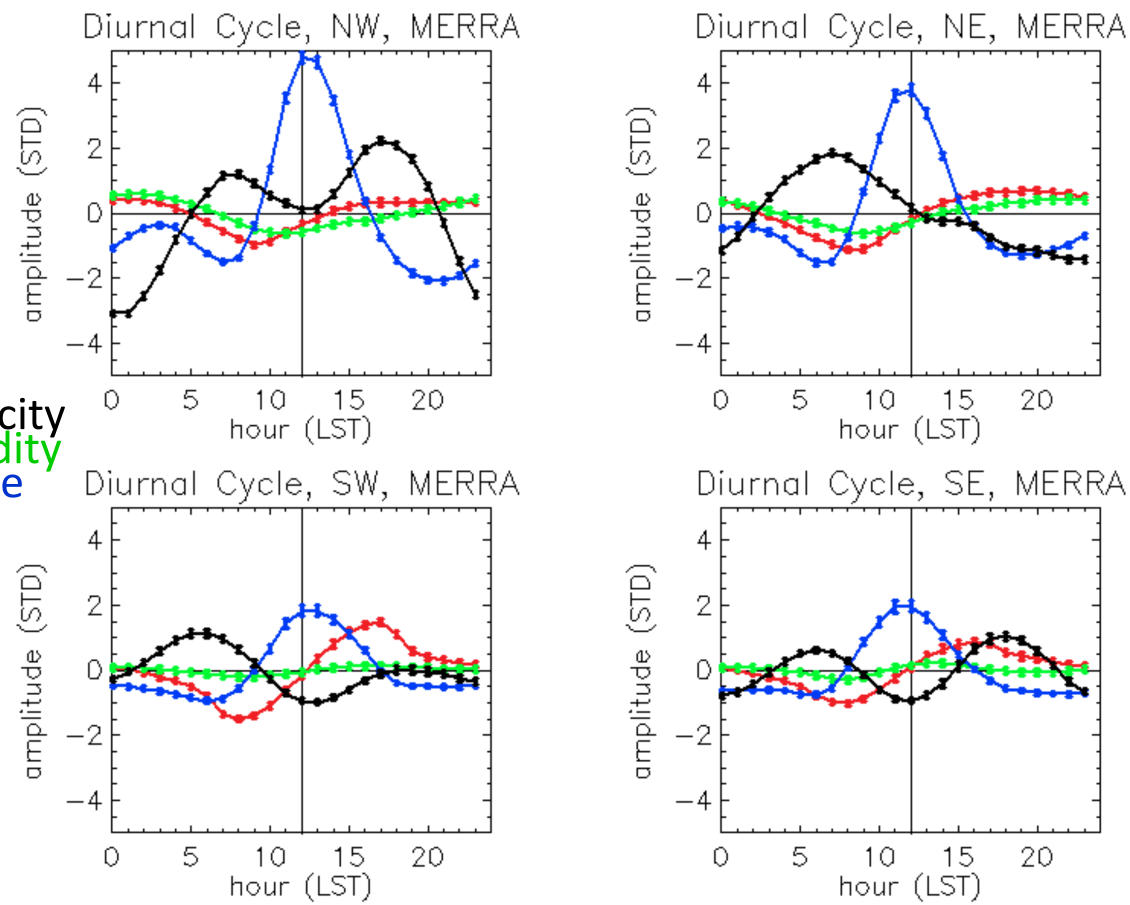
MERRA and GEOS-5 CDCs



- MERRA's errors are inherited from GEOS-5, not observations

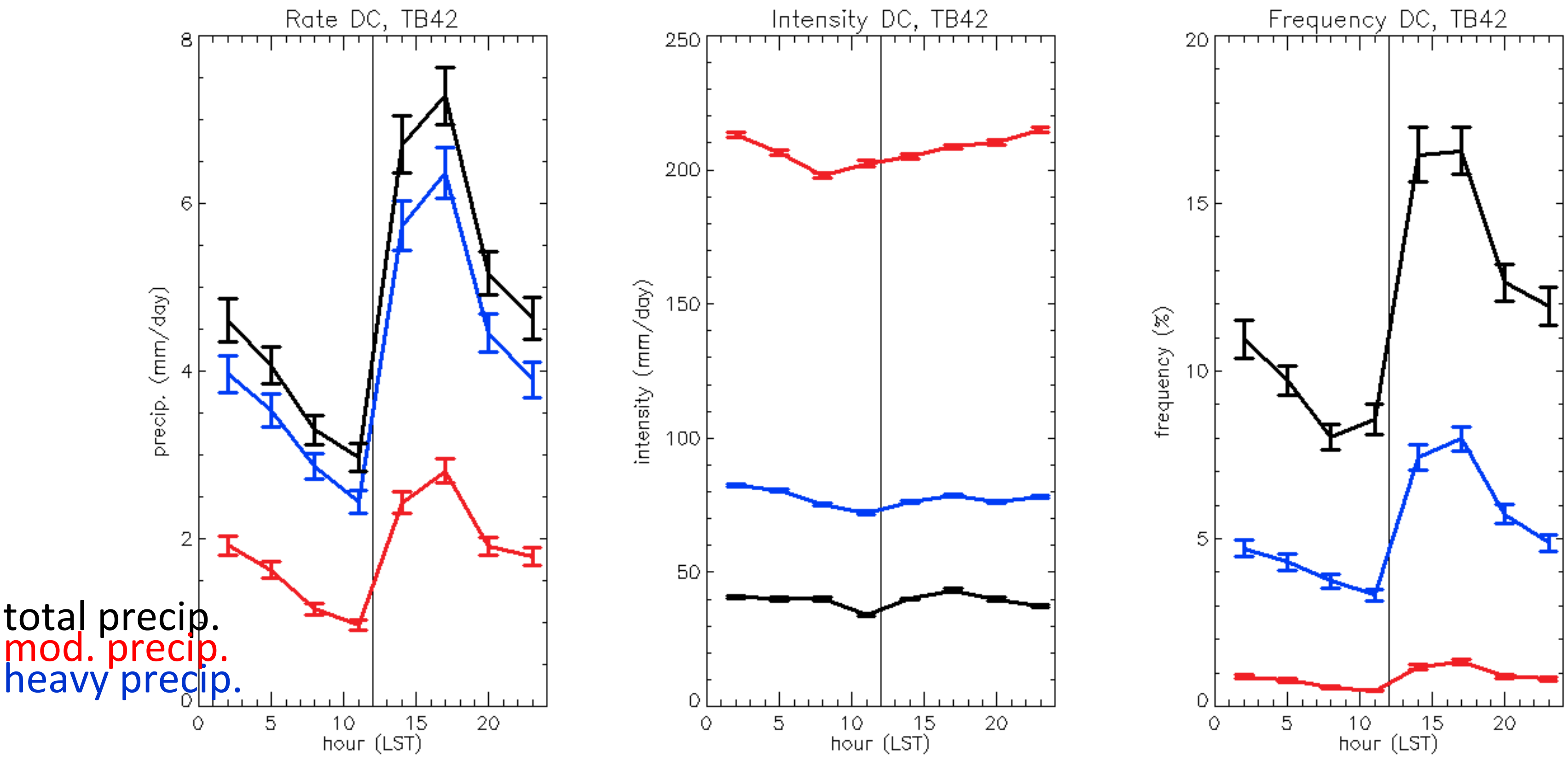
MERRA CDC by Quadrant

500 hPa vert. velocity
250 hPa rel. humidity
surface precip. rate
LW cloud forcing



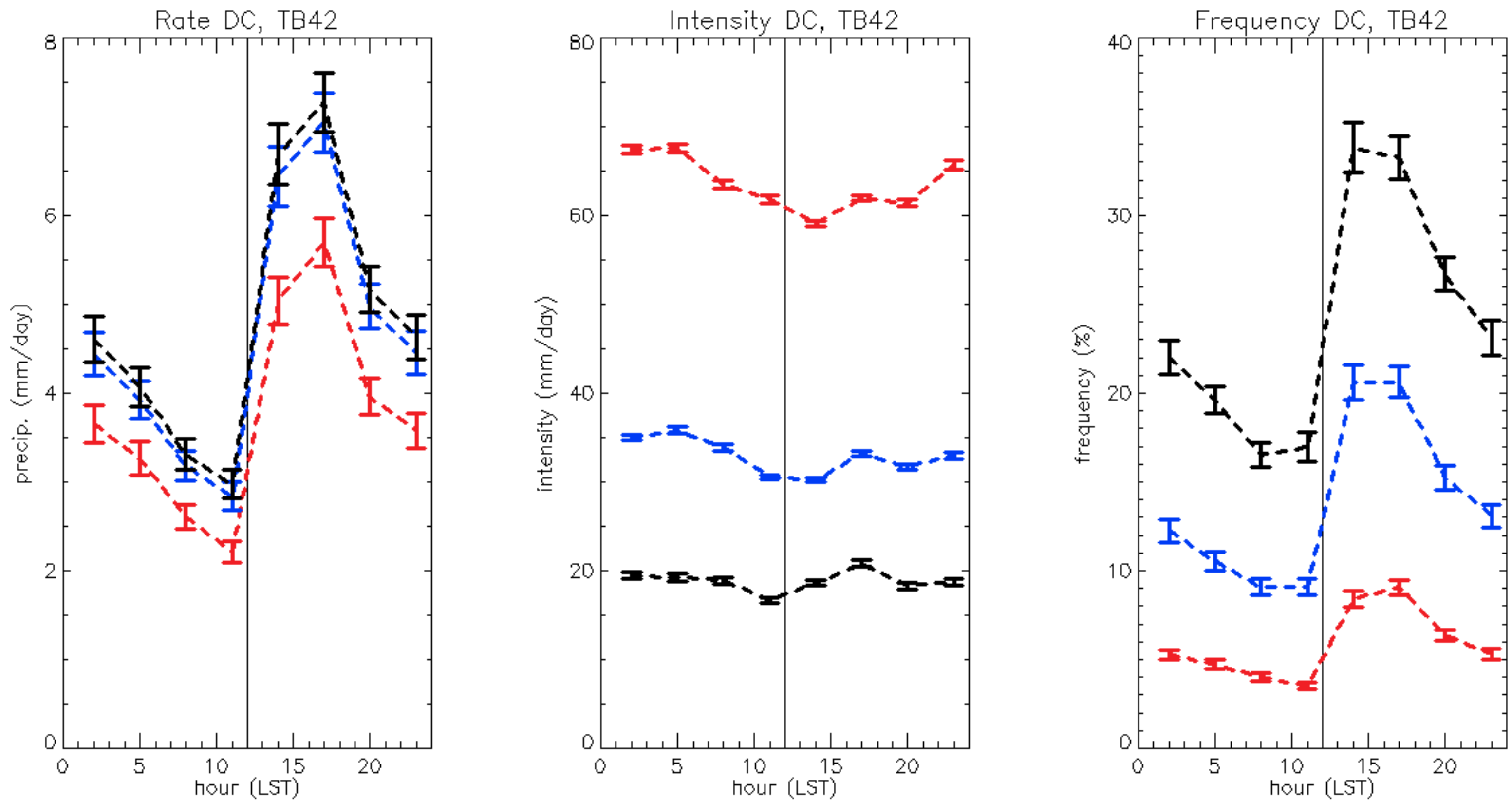
- Split spatial domain into four quadrants (northwest/northeast/southwest/southeast)
- Vert. velocity has semi-diurnal cycle everywhere but NE
- Precip. has secondary max. everywhere

TRMM Precip. by Source and Component



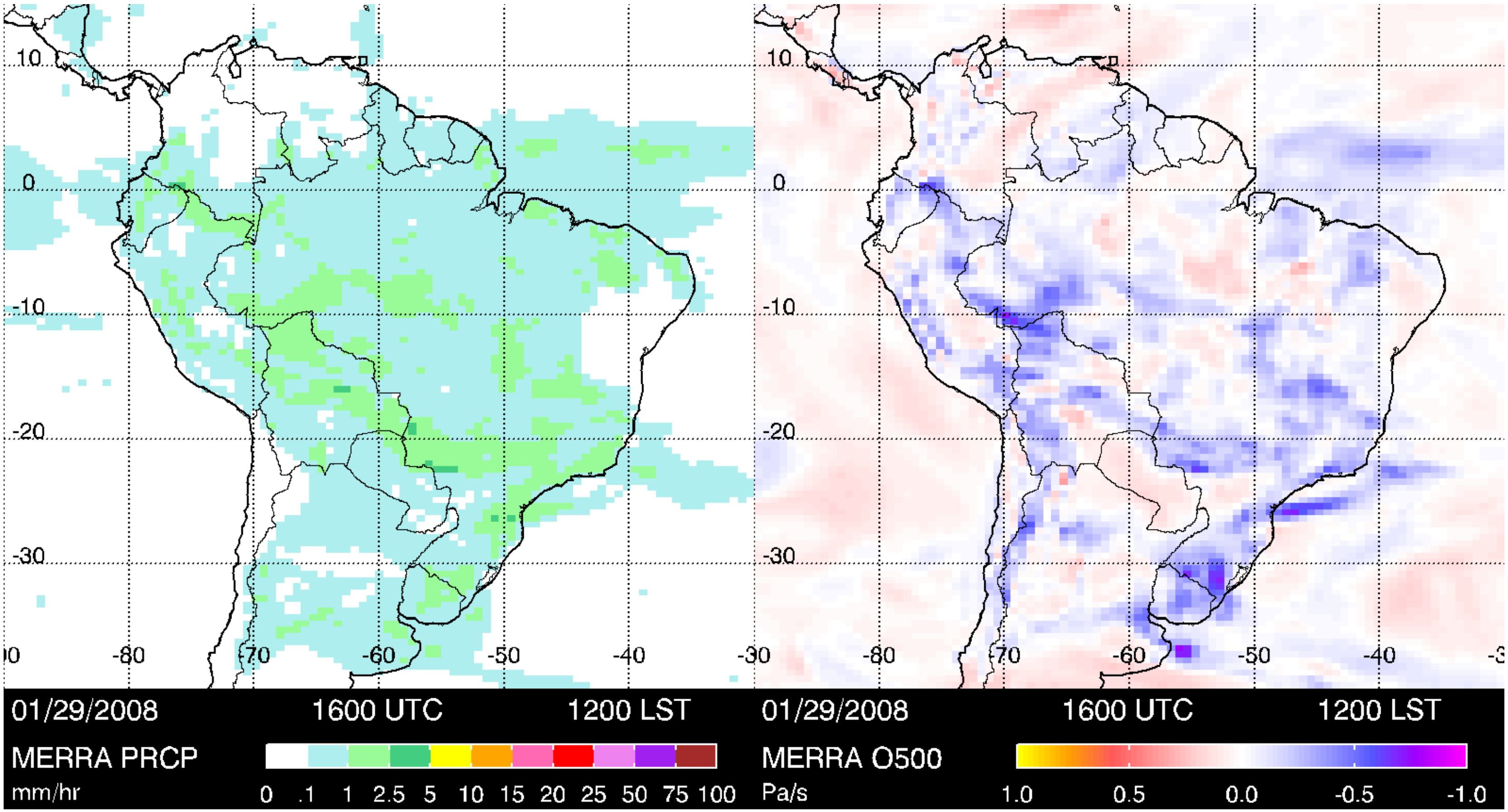
- Observed precip. rate is controlled almost entirely by frequency

TRMM Precip. by Source and Component (MERRA spatial res.)



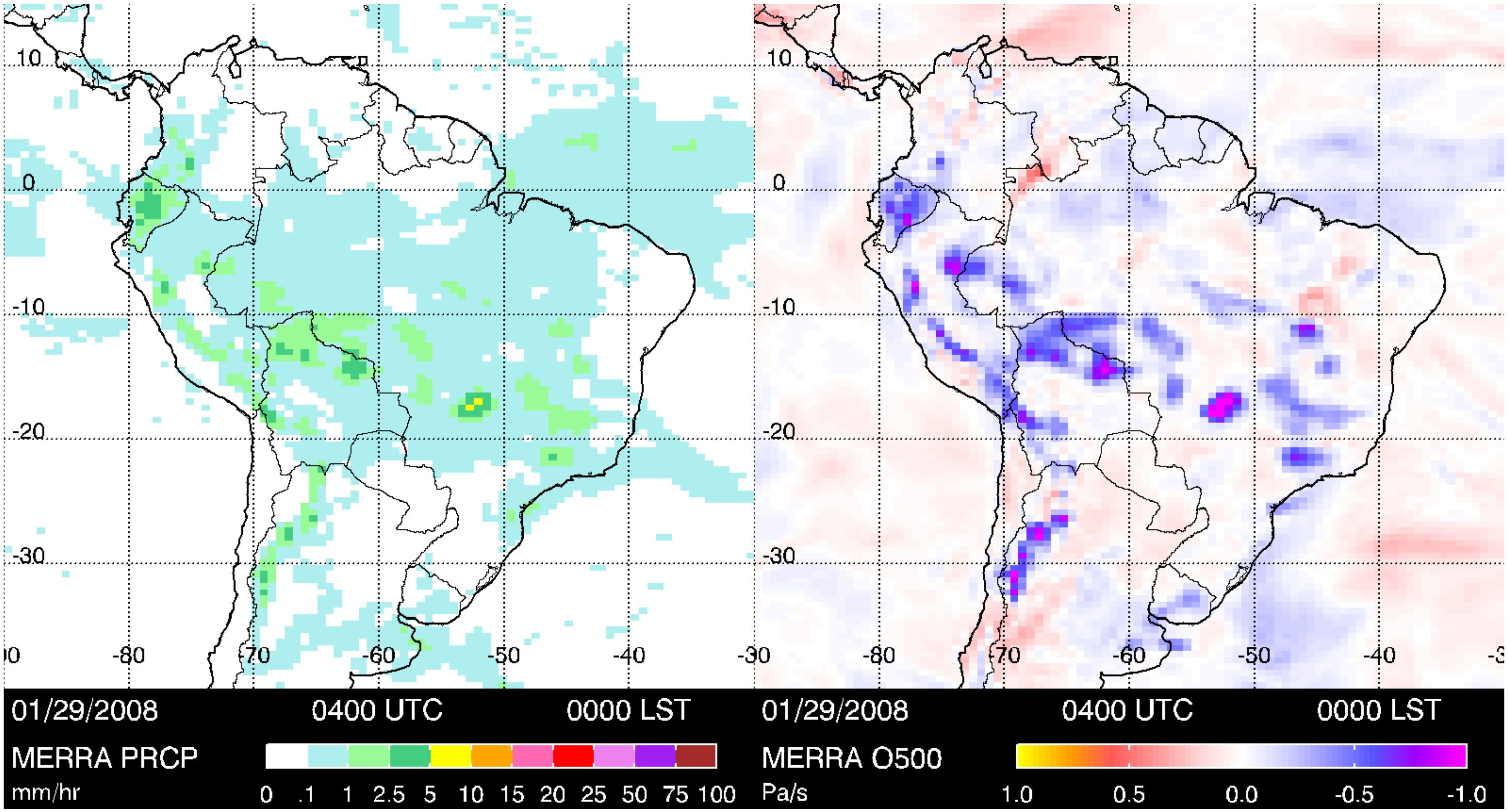
- It is possible that obs./MERRA discrepancy is spatial resolution issue
- However, 3B42 reduced to MERRA's grid shows same result

MERRA Prec. And Vert. Velocity (day)



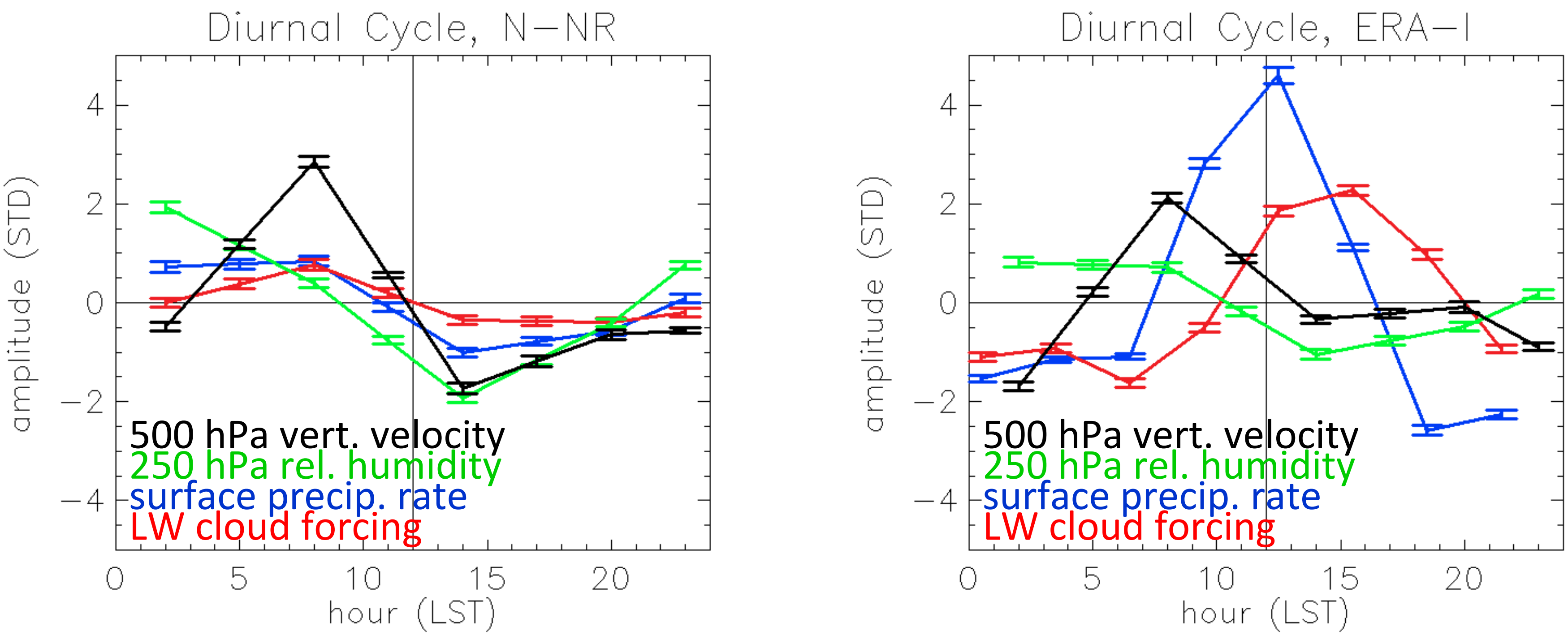
- During day, widespread modest precip. and vertical ascent

MERRA Prec. And Vert. Velocity (night)



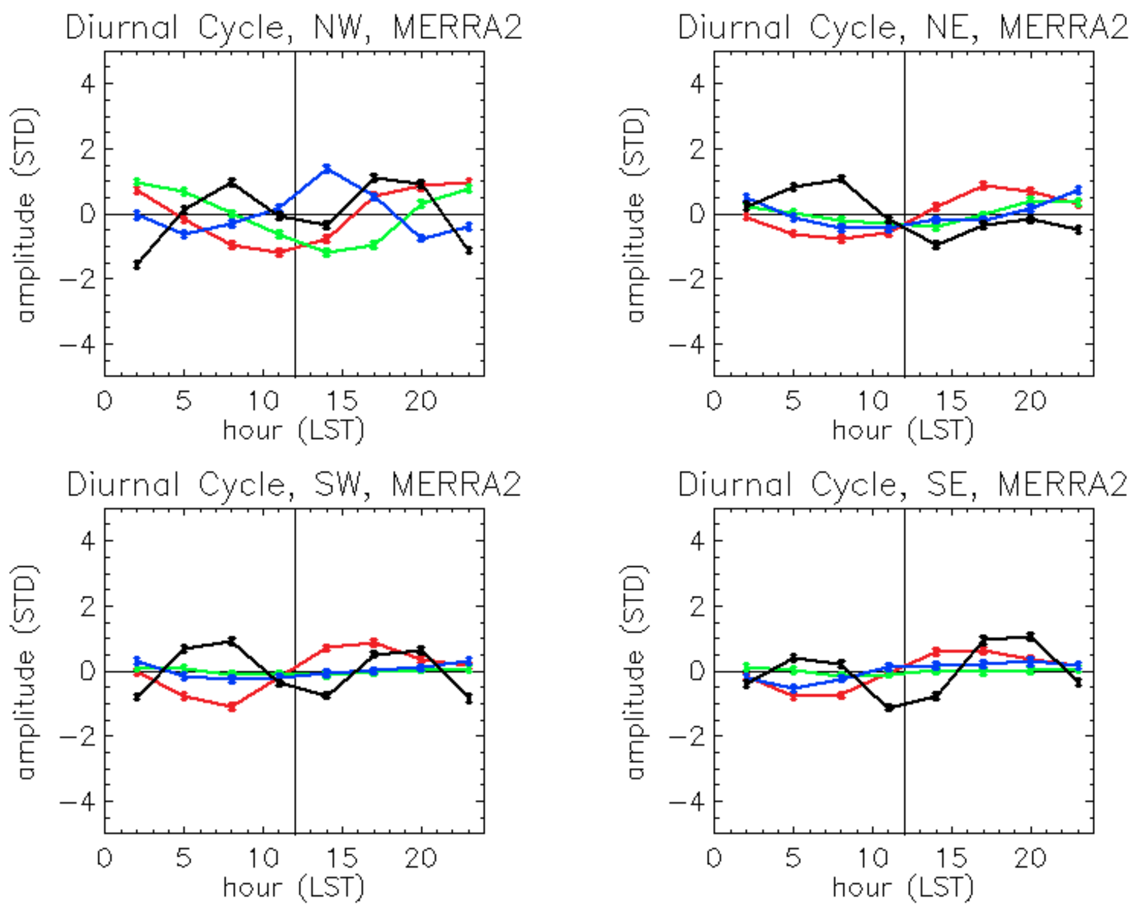
- During night, concentrated precip. and high localized vertical ascent

N-NR and ERA-I CDCs



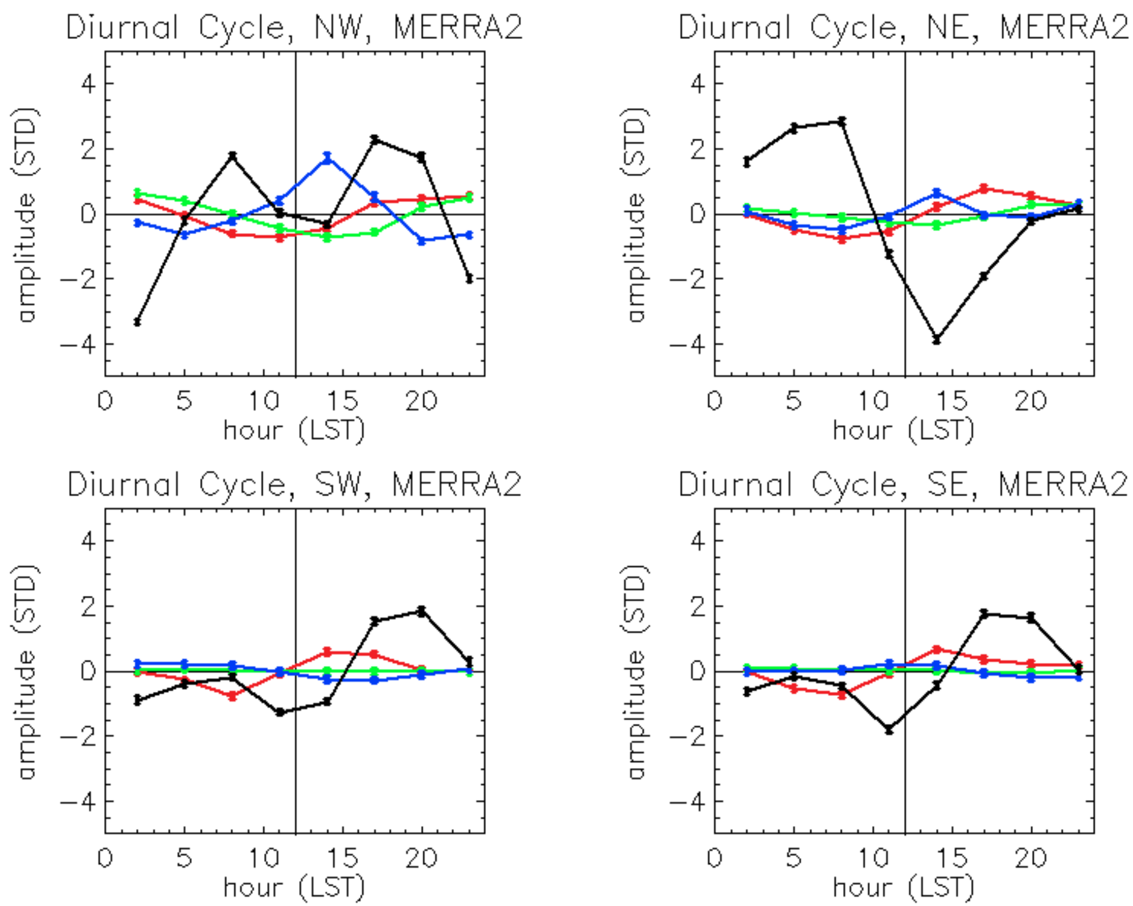
- N-NR has realistic diurnal cycles of UTH and vert. velocity, but misrepresents precip. and LWCF
- ERA-I misses afternoon ascent, where vert. velocity maximizes nocturnally

MERRA2 CDC by Quadrant



- Vert. velocity semi-diurnal cycle exists in all four quadrants in MERRA2

MERRA2 CDC by Quadrant (Dry Season)



- During dry season, NE quadrant has realistic vert. velocity diurnal cycle